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Photoconductor X/γ-ray Detectors and X-ray Bolometers*

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Abstract

Photoconductors are very promising x/γ-ray detectors and x-ray bolometers for pulsed x/γ-ray measurements. They are fast, sensitive and theoretically flat in spectral response for low energy x-rays. We report our tests of InP:Fe, GaAs, GaAs:Cr, both neutron damaged and undamaged, at Nova laser, Febetrons and electron linear accelerators. The temporal and spectral responses are discussed.

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Introduction

Although homogeneous photoconductors have been used as particle detectors for many decades,[1] it is relatively recent that considerable interest has evolved in their use as picosecond γ-ray/x-ray detectors[2-4] and x-ray bolometers,[5] thanks to the advancement of picosecond optoelectronics.[6] Picosecond detection is of interest in the continuing quest for ever higher temporal resolution, while fast bolometer is valuable in the measurement of total output power from a pulsed x-ray source.

We have been investigating various photoconductive semiconductors or insulators (InP:Fe, GaAs, GaAs:Cr, polycrystalline Si, SiO_2 and Al_2O_3) as fast γ-ray/x-ray detectors and x-ray bolometers. In addition to impurity doping, we use radiation damage (neutrons, electrons or γ-rays) to generate recombination sites for controlling carrier lifetime or the decay time of the detector. In this paper, we report some highlights of our investigation.

I. Impulse Response

The experiments were carried out at various pulsed x-ray or γ-ray sources. These include the Nova Laser Facility, electron linear accelerators, Febetrons, a Z-pinch plasma source, the Janus laser and a one-picosecond dye laser.

The most interesting result we have obtained so far is the impulse response of neutron damaged InP:Fe and GaAs to the bremsstrahlung γ-rays from the 17 MeV EG&G Santa Barbara Electron Linear Accelerator. The detectors are 1 mm long, 2.5 mm wide and 0.4 mm thick soldered into a 50 Ω stripline of 2.5 mm width that is connected to coaxial cables on both ends. The signal was taken from one end while the bias was applied from the other.

An example of the impulse response for InP:Fe:n is shown in Fig. 1(a). A similar response was obtained for GaAs:n. For comparison, the impulse response of a Faraday cup in the 17 MeV electron beam is shown in Fig. 1(b). The Faraday cup is known to have a 40 ps full-width-at-half maximum (FWHM) impulse response. It is seen that the InP:Fe:n has an impulse response of < 40 ps FWHM. At 200 V bias, the InP:Fe:n is about 10 times more sensitive than the GaAs:n, and ~60 times more sensitive than the EG&G standard vacuum Compton diode. The InP:Fe and GaAs:Cr without neutron damage have rather long decay times resulting in a FWHM of ~500 ps.

An intriguing effect was observed with Febetrons generating ~100 KeV x-rays of 3 and 30 ns pulse lengths. Fig. 2(a) and Fig. 2(b) compare the responses of InP:Fe and a plastic scintillator (NEIII) on a vacuum photodiode to the 3 ns Febetron x-rays. Clearly, the InP:Fe has a better time resolution revealing a structure within the pulse and also a somewhat shorter FWHM. Note that the tails are very similar. The pictures changed dramatically at the 30 ns Febetrons as shown in Fig. 2(c) and Fig. 2(d). For the InP:Fe not only the FWHM is larger but the tail is also much larger than NEIII. The neutron damaged InP:Fe:n on the other hand showed not only a very narrow FWHM but also fully resolved two peaks on the falling side of the pulse due to the excellent resolving time. In addition, the long tail as seen in Fig. 2(c) is completely gone.

The results shown above indicate that the neutron damaged InP:Fe, GaAs, GaAs:Cr have excellent resolving time (<40 ps) and good response to hard x-rays of relatively long pulse (30 ns). There is little doubt that these detectors should remain good for longer pulses.

The response of InP:Fe to low energy x-rays from the Nova target is shown in Fig. 3. This is a 1mm x 1mm x 1mm InP:Fe photoconductor biased at 100V and located at 440 cm from the target. A 1.06 μm, 1.5 kJ and 1 ns Nova beam were focused onto a gold disk target at 3×10^{14} W/cm^2, and the x-rays were filtered with a 25 μm Aℓ filter. The impulse response is good and the detector sensitivity is quite remarkable.

II. Spectral Response

According to Shockley,[7] the average energy required to produce an electron-hole pair in a solid is independent of both the energy and the mass of the incident particle. If the particle stops in the solid, the total energy is converted into electron-hole pairs, the number of which is proportional to the incident energy. Thus for stopping particle, the charges collected or the pulse height is proportional to the energy of the particle. The argument applies to x-rays, namely if the photoconductor totally absorbs the x-rays, the pulse height should be proportional to the energy of the x-rays. Thus, the photoconductor should theoretically have a flat spectral response to x-rays. Unlike the semiconductor junction detectors (such as pin diode, surface-barrier diode or Li-drifted detectors), the photoconductors may be made free of dead layers and, thus, can be utilized as low energy x-ray bolometers. The spectral response of InP:Fe appears to be flat for 0.7-3 keV x-rays within experimental uncertainties.[5]

At Nova, we plan to calibrate the spectral response of photoconductors to 100-500 eV x-rays, utilizing the filter-mirror channels of a broadband low-energy x-ray spectrometer.

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Figure Captions

1.(a) The impulse response of a neutron-damaged InP:Fe:n to bremsstrachlung γ-rays from a 17 MeV electron linear accelerator.

1.(b) The impulse response of a 40 ps Faraday cup in the 17 MeV electron beam.

2.(a) The response of InP:Fe to the 3 ns Febetron x-rays.

2.(b) The response of a plastic scintillator (NEIII) on a vacuum photodiode to the 3 ns Febetron x-rays.

3. The response of InP:Fe to low energy x-rays from a Nova target.

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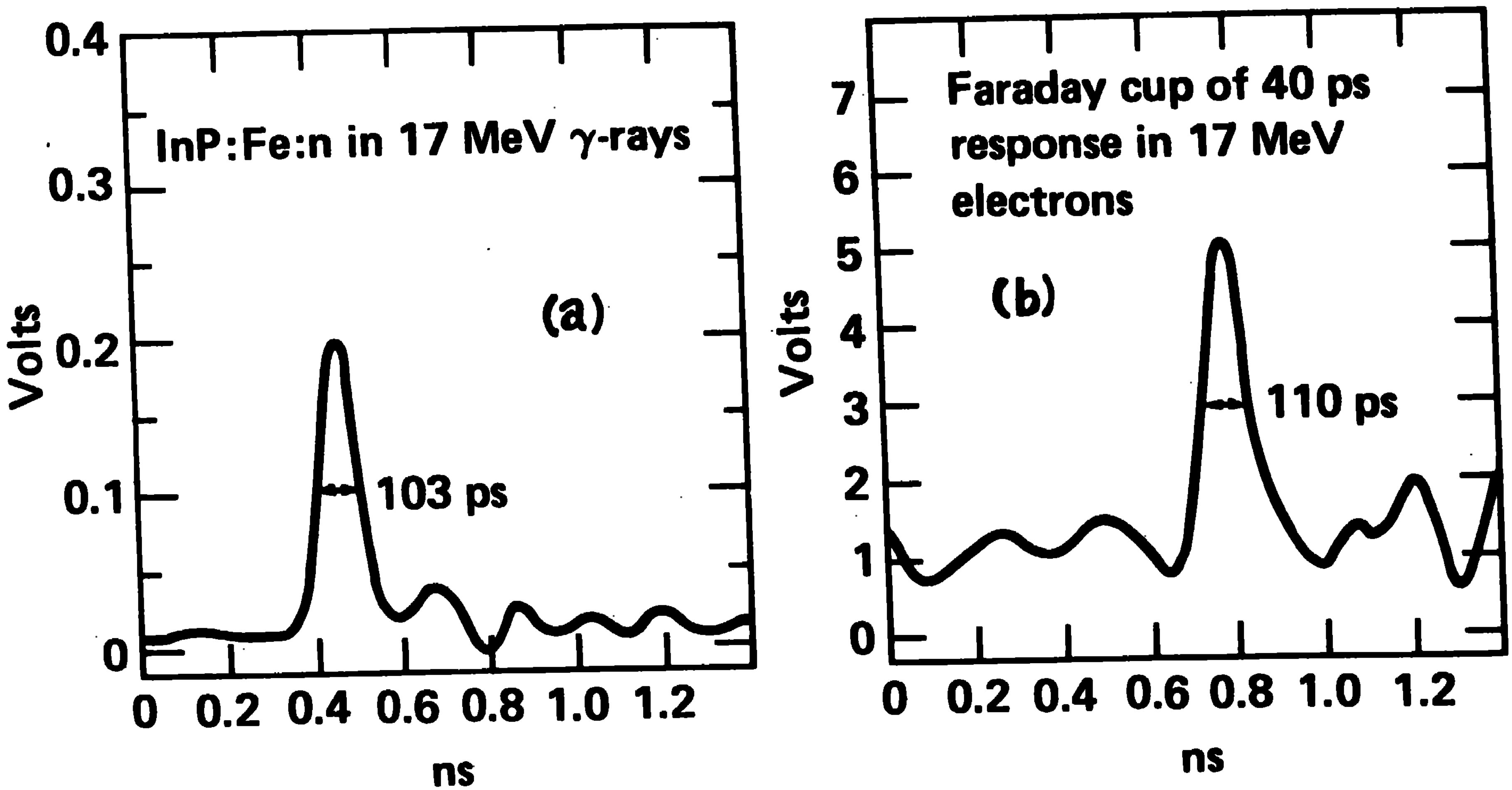

Fig. 1

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Impulse responses of photoconductor and plastic scintillator to 100 keV x-rays

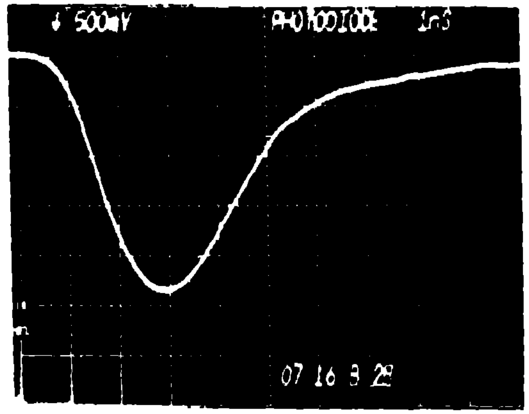
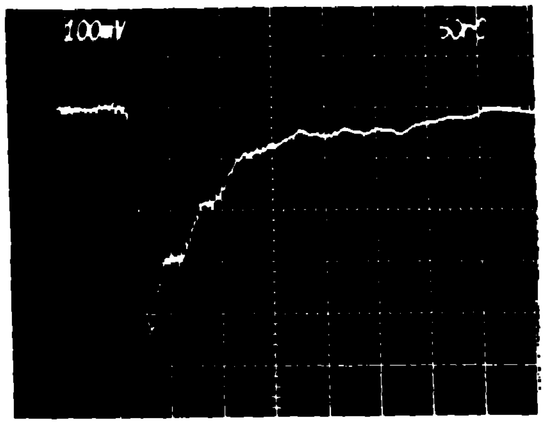
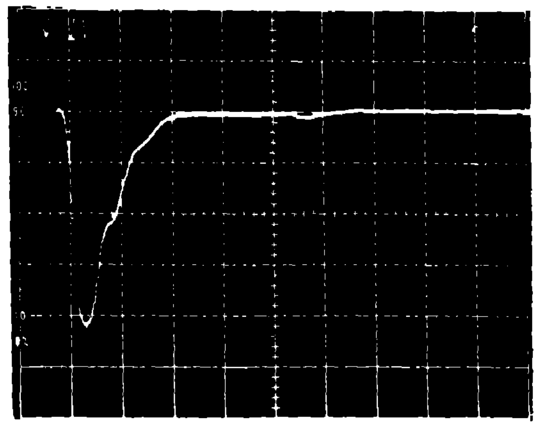
		Photoconductor InP:Fe		Plastic scintillator NEIII
3 ns Febetron	(a)		(b)	
		1 ns/div.		1 ns/div.
30 ns Febetron	(c)		(d)	
		50 ns/div.		50 ns/div.

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Fig. 2

Impulse response of photoconductor to low energy x-rays from Nova target

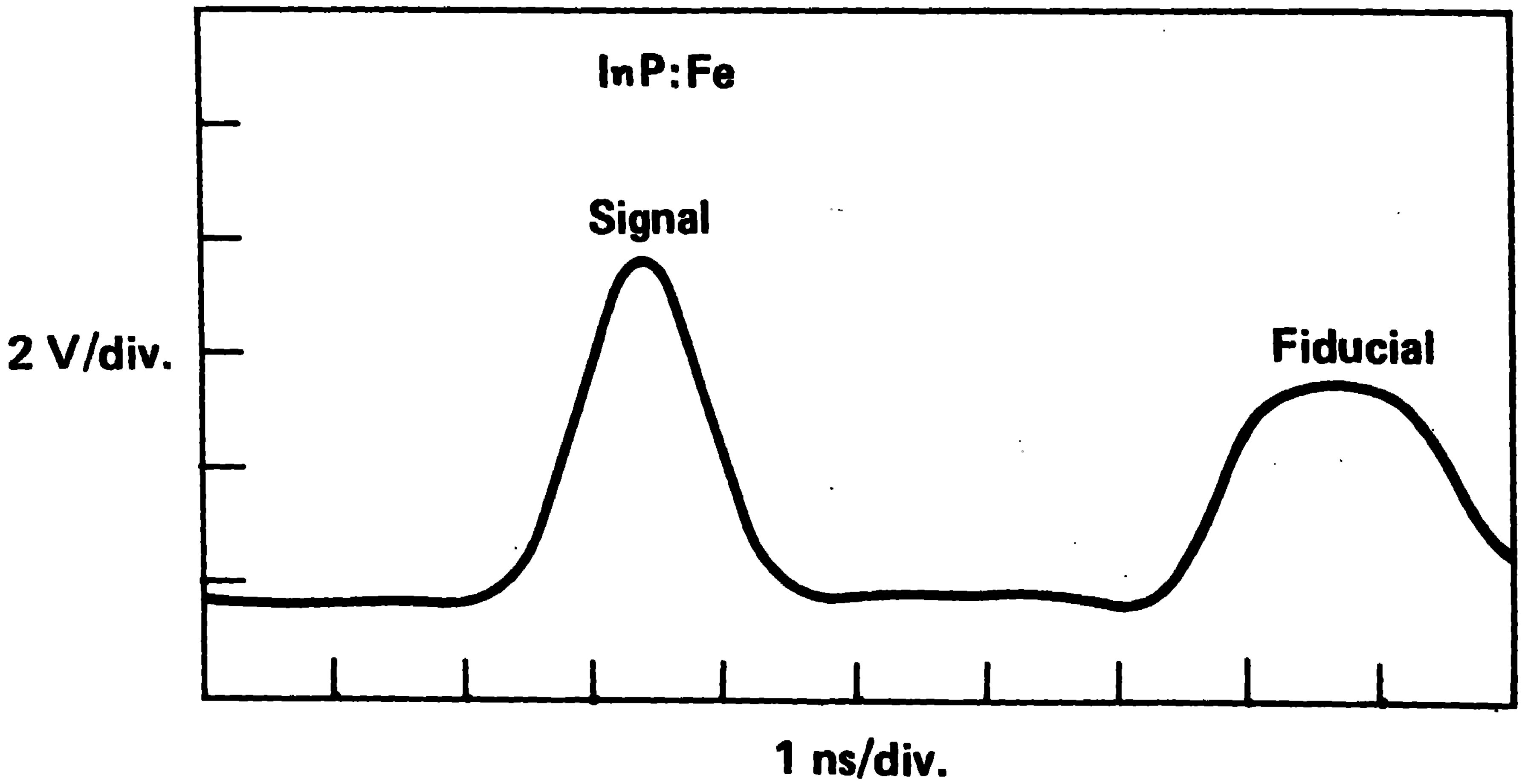

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Fig. 3